ELSEVIER

Catena 50 (2003) 135–150

CATENA

www.elsevier.com/locate/catena

Quantifying historical gully erosion in northern Bavaria

Markus Dotterweich*, Anne Schmitt, Gabriele Schmidtchen, Hans-Rudolf Bork

Ecosystem Research Centre, University of Kiel, Olshausenstr. 40, D-24098 Kiel, Germany

Received 20 September 2000; received in revised form 30 January 2001; accepted 22 February 2001

Abstract

The Wolfsgraben is one of many ravines that cut into the silty–sandy material of the Triassic benchlands of northern Bavaria, Germany. Within the research area, a gully—several meters in depth—has carved in to a bluff 500 m west of the upper Main valley. An analysis of 17 exposures and 30 drillings was conducted within the gully and its colluvial fan in order to reconstruct the soil formation, extreme rainfall events and land use changes throughout history.

Detailed field studies, chemical soil analysis, dating methods of charcoal and pottery, as well as written documents were combined to produce a high-resolution stratigraphy.

Nine main phases of landscape evolution, caused by extreme rainfall, runoff and soil erosion in agriculturally used areas, have been identified since the medieval period. The highest amount of soil loss occurred during 14th, 18th and 19th centuries, a result of intensive land use. Climate changes affected the intensity of rainfall and the magnitude of soil loss during these periods.

Keywords: Land use; Gully erosion; Landscape evolution; Erosion rates; Climate changes; Bavaria

1. Introduction

To quantify historical soil losses, it is necessary to find suitable sedimentation traps in small catchments. This article describes an interdisciplinary investigative approach for a refilled gully system, which has cut itself into a small valley in northern Bavaria, Germany.

* Corresponding author. Tel.: +49-431-880-4002; fax: +49-431-880-4083.
E-mail address: mail@markus-dotterweich.de (M. Dotterweich).
URL: http://www.markus-dotterweich.de.

0341-8162/03/$ - see front matter
PII: S0341-8162(02)00142-X

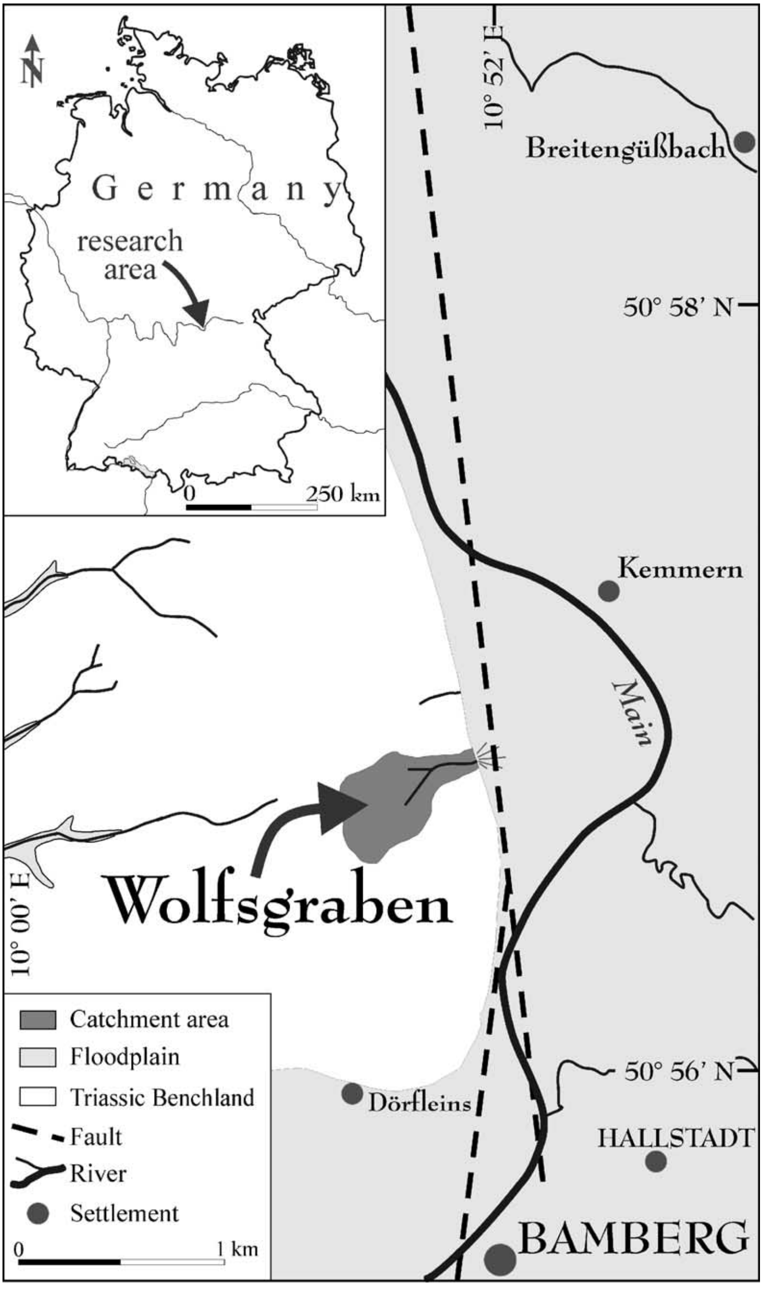

Fig. 1. The situation of the Wolfsgraben (source: Geological map of Bavaria 1:25.000, sheet no. 6031, Bamberg Nord).

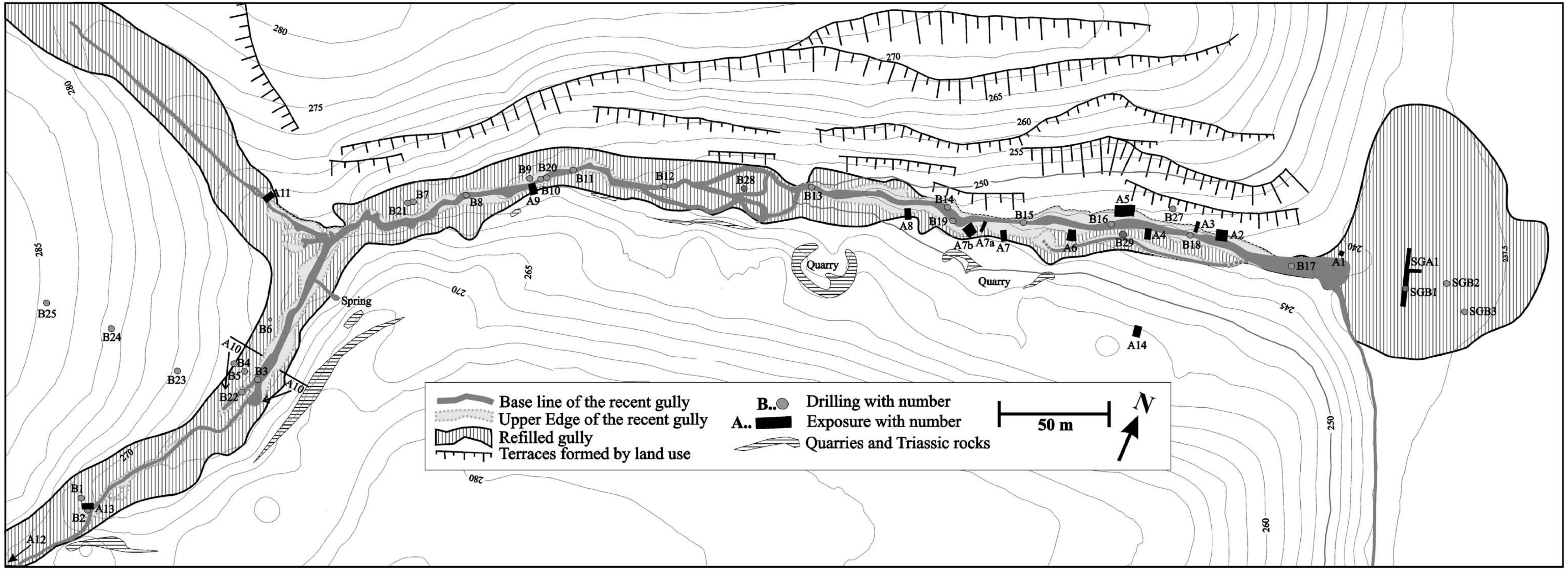

Fig. 2. Survey map of the Wolfsgraben.

Around 5000 B.C., the first Neolithic farmers settled in northern Bavaria (Züchner, 1996, p. 54). At this time, man started to change the environment significantly. Because of the growing population in the medieval period, extended forest clearing for arable land was necessary. The soil was now no longer protected and heavy rainfall events eroded the fertile topsoil. With the declining soil fertility, crop failures occurred more frequently causing malnutrition. As a result, starvation and epidemic diseases increased, leading to a decrease in population density (Bork et al., 1998). The sediments of the terraces in the valleys of the rivers Main and Regnitz in northern Bavaria mirror this pattern of soil erosion, sedimentation and land use history (Schirmer, 1983).

2. Materials and methods

An interdisciplinary approach was used to investigate the impact of land use changes and extreme rainfall events on soil erosion processes and gully development during the late Holocene. The approach consisted of detailed field studies, examination of drillings and soil exposures, dating methods and chemical soil analysis, as well as studies of contemporary maps and documents. In 1999, 17 exposures (depth up to 3 m) and more than 27 drillings (depth up to 5 m) were investigated in the catchment area, the infillings of the ravine and the colluvial fan of the Wolfsgraben (Dotterweich et al., 2002). Chemical analyses of organic matter, phosphate, Al, Mn, Fe and heavy metals (Cu, Pb, Zn, Cd and Cd) were carried out. ^{14}C-dating of charcoal and archaeological dating of pottery helped to identify the ages of soil accumulations and soil formations. The detailed analysis of contemporary documents and maps revealed the history of land use. Precise field surveying of the investigation area using a “Field Total Station” was necessary to quantify soil erosion. The synthesis of all methods described above led to a complex stratigraphy.

3. General situation

The Wolfsgraben (N: 49°56′ 49″, E: 10°51′ 53″) is situated near the village of Kemmern, 10 km north of the city of Bamberg (Fig. 1). The catchment area measuring 0.45 km^2 extends from the floodplain of the river Main 500 m upslope to the hilly areas of the Triassic benchland. The slopes of the Wolfsgraben are 30 m deep, and today, they are covered by forest. The soils are loamy and sandy; cambisols being dominant. The annual precipitation totals 650–700 mm year^{-1} and the mean temperature ranges from 7 to 8 °C (Climatic map of Bavaria 1:2.500.000, 1955). The main encarvation of the Wolfsgraben was caused by the gradual lowering of the valley of the river Main. This took place during the Pleistocene (Büdel, 1957, p. 34; Rohdenburg, 1971, p. 248).

Along the thalweg of the Wolfsgraben, a refilled gully is present. A younger gully with a length of 350 m and a maximum depth of 3 m has cut into the sediments. Most of the year, water runs through the gully. The fresh walls of the recent gully enabled us to investigate the sediments of the Wolfsgraben (Fig. 2). Under the deciduous forest, five land use terraces caused by former ploughing can be seen at the southward-facing slope. On the northward-facing slope, some abandoned quarries of the 18th/19th century are still remaining. A detailed analysis of Wolfsgraben's land use history is described in Schmitt (1999).

4. Results

The basic shape and the amount of colluvial sediments could be quantified by investigating the exposures and drillings in the Wolfsgraben (Figs. 2 and 3). Before the recent gully carved into the surface, the amount of sediments of the Wolfsgraben deposited during the younger Holocene between its gully head (Exposure no. 10) and Exposure no. 2 totalled approximately 4960 m^3. The recent gully eroded approximately 1180 m^3 between Exposure nos. 10 and 2. The catchment covers between these two points an area of 7.2 ha. Assuming that the sediment input into this area is the same as the sediment output, it is possible to quantify the soil and gully erosion of earlier times.

Exposure no. 10 (Fig. 4) shows the recent amphitheatre-shaped area of the gully head with sediments of more than 20 different layers of gravel, sand, loam and silt. The sediments from the lower part of the sandy–silty Triassic sandstone can be found at the northward-facing slope. The sediments at the bottom of the exposure (approximately 1 m

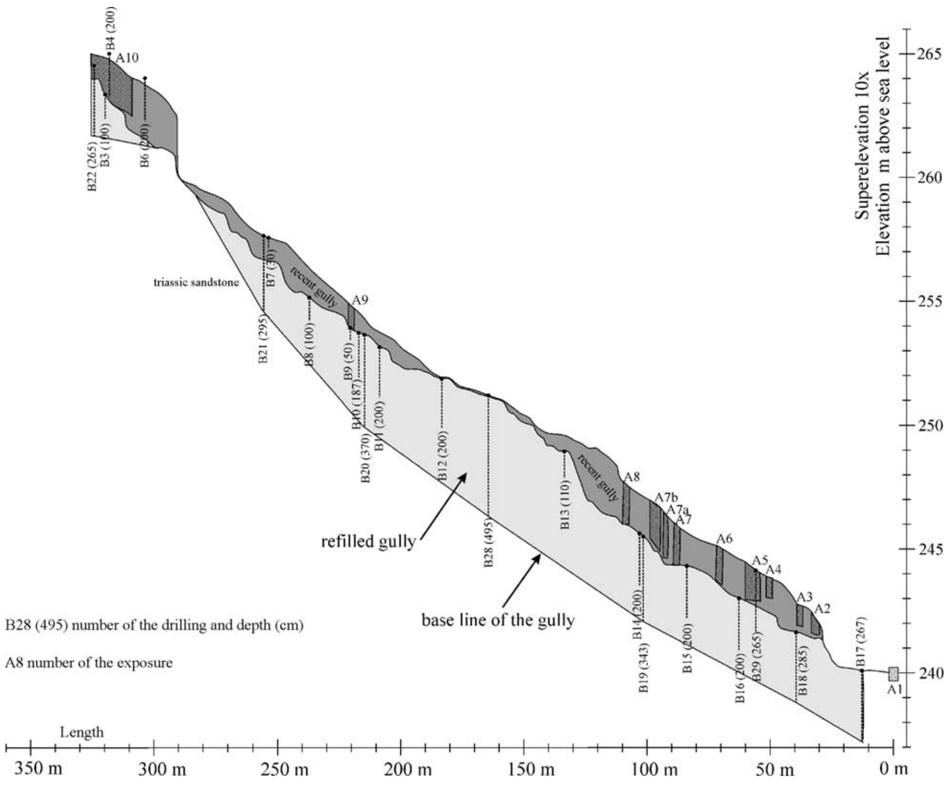

Fig. 3. Profile through the thalweg of the "Wolfsgraben."

Fig. 4. Exposure no. 10.

above the basis of the origin sandstone) included some pieces of pottery which date back to the latter half of the 15th century (archaeological dating: Dr. J. Haberstroh, Bavarian State Department of Historical Monuments, May 27, 1999) and many hundred pieces of charcoal. The first meter of sediment in the exposure is red silt originating from the lettic southward-facing slopes.

Exposure no. 8 (Fig. 5) reveals a 2.5-m deep exposure at the southern wall of the recent gully. The lowest part shows loamy–sandy sediments (layers 1–4). Inside of layer 4, two pieces of pottery were found dated to the 17th/18th century (archaeological dating: Dr. J. Haberstroh, Bavarian State Department of Historical Monuments, Sept. 27, 1999). Above layer 4 follows a small silty black soil horizon containing 12% of organic matter. On top, there is a very hard and stony layer (no. 6), possibly an old track to the quarries located at the north facing slopes. The last 1.2 m contains gravel and sand rubble from the quarries. The exposures of the lower part of the gully are mostly silty–sandy. In these sediments, more than 15 pieces of pottery were found from the 17th/18th centuries. By means of a 25- and 2-m large exposure SGA1 (Fig. 2) on the colluvial fan of the Wolfsgraben, the sediments deposited from the recent gully were investigated. More than 20 pieces of pottery from the 17th/18th centuries could be identified in the 13 sedimentation layers.

In the sediments of drilling No. 21, some pieces of charcoal were found approximately 20 cm above the Triassic sandstone basis. The ^{14}C-dating revealed an age of 317 ± 29 B.P. (two sigma cal A.D. 1480–1694; Leibniz Labor, University of Kiel, KIA 8550, according to CALIB rev4.0, test version 6 (Datasets 1), Stuiver et al., 1998). The sediments in the drilling No. 28 have a thickness of 495 cm. A piece of pine bark 407 ± 26 B.P. in age (two

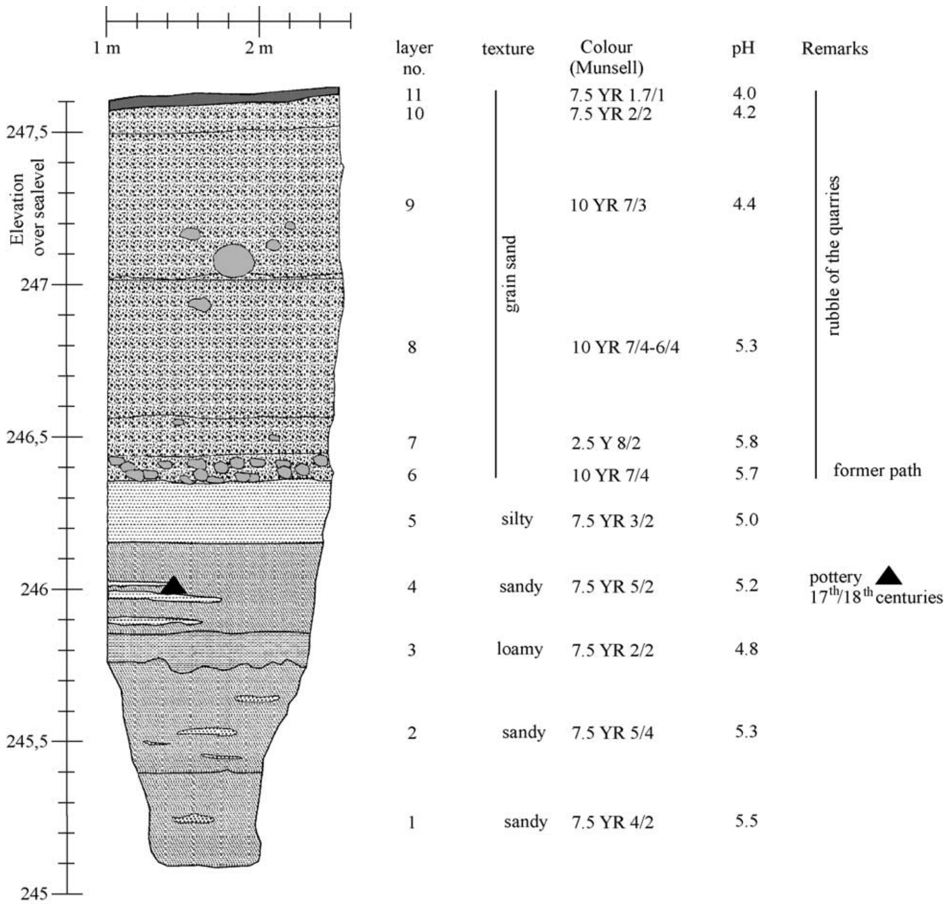

Fig. 5. Exposure no. 8.

sigma cal A.D. 1437–1510, 1600–1613; Leibniz Labor, University of Kiel, KIA 8549) was discovered 1.75 m above the basis.

Nine main phases of landscape development of the Wolfsgraben were distinguished.

Phase 1: During the Pleistocene, the Wolfsgraben carved into the Triassic benchland following the lowering of the river Main (Büdel, 1957, p. 34).

Phase 2: At the end of the Pleistocene, a natural forest grew preserving the existing topography. A Cambisol developed (Fig. 6, left above).

Phase 3: From approximately 1200 B.C. until Roman times, the settlements in the valley of the river Main and on the hills were increasing in number (Abels et al., 1996, pp. 88–89). The catchment area of the Wolfsgraben gives no evidence of the land use changes of Phase 3. At this time, a lot of loamy and silty sediments accumulated in the valleys of the river Main, a result of soil erosion from the slopes (Schirmer, 1983, p. 40). After approximately 500 A.D., the population and settlements decreased rapidly in northern Bavaria (Abels et al., 1996, p. 186).

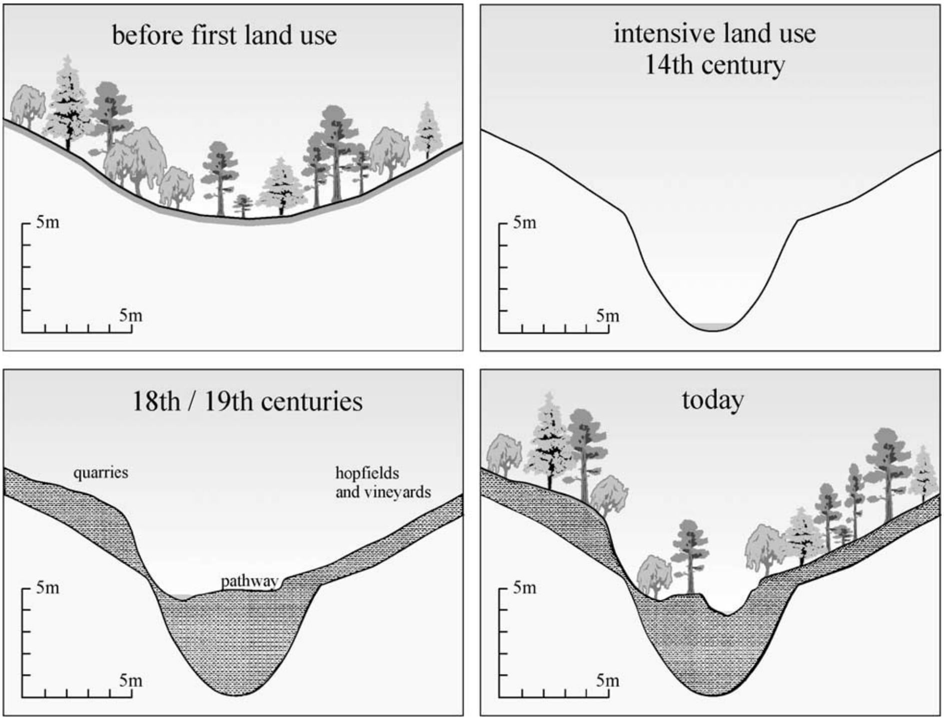

Fig. 6. Main phases of the landscape evolution of the "Wolfsgraben."

Phase 4: The land use intensity again rapidly increased after 700 A.D. Many villages around the investigation area were founded. As the city of Bamberg increased in size, many slopes were deforested (Schmitt, 1999). In the 14th or early 15th century, the first major postglacial landform change occurred. Due to intensive land use and an extreme rainfall event, a several meter deep gully carved into the surface removing the Pleistocene sediments as well as the soil along the thalweg (Fig. 6, right above). The base line of this gully is represented in Fig. 3.

Phase 5: After the significant event of Phase 4, some small landslides occurred at the edge of the gully. The gully was then filled with sediments from the slopes. Exposure no. 10 (Fig. 4, front of the picture) shows these sediments.

Phase 6: Due to the German War between 1618 and 1648, the land use in the catchment area was kept at a low level (Schmitt, 1999).

Phase 7: Until the first half of the 18th century, the land use intensity in the Wolfsgraben area increased again. Soil erosion in the catchment area occurred. The sediments were deposited along the thalweg (Fig. 5; Exposure no. 10, Fig. 4). On the northward-facing slope, sandstone mines existed. At this time, a track (Exposure no. 8, layer no. 6) ran through the thalweg of the Wolfsgraben (Fig. 6, left down).

Phase 8: During a large rainfall event, the recent gully, featuring an average depth of 1.6 m, cut through the medieval sediments along the track in the Wolfsgraben. Fig. 3 represents the "recent gully" and Exposure no. 10 of Fig. 4 shows the active gully head.

Phase 9: With the ongoing removal of the topsoil, the fertility of the slopes in the catchment decreased dramatically. Together with the destruction of the track, the fields were converted into pasture, and today, almost the entire catchment is covered by forest (Fig. 6, right down).

From the volume of the colluvial material, we calculated the total hillslope erosion between Exposure nos. 2 and 10 for interval in-between the 14th and the 17th centuries to be approximately 70 mm (i.e. 2.8 t/(ha year) or 0.17 $year^{-1}$). The latest linear erosion event eroded a volume of 1180 m^3, most of which was deposited in the colluvial fan.

5. Conclusions

Today, over 5 m of late Holocene sediments cover the Triassic sandstone base of the recent thalweg of the Wolfsgraben. The first major gullying took place in the late medieval period (Phase 4). In the first half of the 14th century, a great pressure towards intensive farming in Central Europe existed. In northern Bavaria, most of the hills were used as arable land or pasture. The few remaining forests were intensively exploited for wood production and grazing. This land use scheme could have had significant effects on the regional climate, resulting in a higher number of weather extremes (Bork et al., 1998). Extreme rainfall events

Fig. 7. Memorial stone of the mega flood in 1342 (printed with friendly permission of the "Mainfränkisches Museum Würzburg" inventory no. 43087). "On the twelfth day before the calendars of August AD 1342, on the Sunday before Jacobi, the river Main rose as high as never before. The water level reached the steps of the cathedral of Würzburg and flowed around the first stone statues. The bridge with the tower, the walls and many stone houses in Würzburg collapsed. In the same year there were similar floods all over Germany and in other regions. And this house was built by master Michael of Würzburg."

occurred in the first half of the 14th century and to a lesser extent during the latter half of the 18th century. With these heavily erosive events, the soil fertility on the slopes decreased dramatically. Tracks and slopes were gullied and the lower slopes were covered with sediments. Consequently, yields were then on a very low level. Presumably, this was the cause for malnutrition, causing rapid spread of epidemics and resulted in a decline in population density. As land use pressure on the environment ceased, the ecosystem regained stability. We assume that the first gullying in the Wolfsgraben took place in the first half of the 14th century, namely around July 21, 1342. This day witnessed the largest recorded flood in Central Europe (Bork et al., 1998). It destroyed the bridges across the river Main in Bamberg and Würzburg (approximately 70 km downstream) as well as many others in Germany. Medieval documents containing information on weather events are very rare. The Mainfränkisches Museum Würzburg exhibits a memorial stone of the flood (Fig. 7).

The Wolfsgraben scenario shows the complex interaction between land use, soil erosion and climatic change. Without the intensive land use practices, the soil would have been better protected against extreme rainfall and runoff events. Furthermore, it is difficult to assess to what extent the massive deforestation influenced the climate and the increase in extreme weather events on a regional scale. To broaden our understanding of these issues, more research will be undertaken at a number of locations throughout the region.

Acknowledgements

The following persons are gratefully acknowledged:

- Dr. F. Schäbitz, University of Bamberg, Department of Geography;
- J. Haberstroh, Bavarian State Department of Historical Monuments, Schloß Seehof, Bamberg;
- Prof. Dr. M. Fürst, Hallstadt;
- H. Bork;
- the students of the Universities of Potsdam and Bamberg;
- Dr. F.K. Rupprecht and Dr. S. Nöth, Staatsarchiv Bamberg;
- E. Schreiber, Stadtarchiv Hallstadt;
- E. Schmitt, G. Schmitt and M. Schmitt;
- Cusanuswerk for financial assistance.

References

Abels, B.-U., Sage, W., Züchner, Ch., 1996. Oberfranken in Vor- und Frühgeschichtlicher Zeit. 2. Auflage. Bayerische Verlagsanstalt, Bamberg. 304 pp.

Bork, H.-R., Bork, H., Dalchow, C., Faust, B., Piorr, H.-P., Schatz, T., 1998. Landschaftsentwicklung in Mitteleuropa. Wirkungen des Menschen auf die Landschaften. Klett–Perthes, Gotha. 328 pp.

Büdel, J., 1957. Grundzüge der klimamorphologischen Entwicklung Frankens. In: Büdel, J. (Ed.), Beiträge zur Geographie Frankens. Festschrift zum 31. Deutschen Geographentag in Würzburg 29. Juli bis 3. August 1957. Würzburger Geographische Arbeiten, vol. 4/5. Geographisches Institut, Würzburg, pp. 5–46.

Climatic map of Bavaria (Klimakarte von Bayern) 1:2.500.000, 1995. Bodenkundliche Übersichtskarte von Bayern 1:500.000. Bayerischen Geologisches Landesamt, München, Germany.

Dotterweich, M., Schmitt, A., Bork, H.-R., 2002. Jungholozäne Bodenerosion und Kerbenentwicklung im Wolfsgraben bei Bamberg. In: Bork, H.-R., Schmidtchen, G., Dotterweich, M. (Eds.), Bodenbildung, Bodenerosion und Reliefentwicklung im Mittel- und Jungholozän. Forschungen zur deutschen Landeskunde (in press).

Rohdenburg, H., 1971. Einführung in die klimagenetische Geomorphologie. Lenz, Gießen. 350 pp.

Schirmer, W., 1983. Die Talentwicklung an Main und Regnitz seit dem Hochwürm. In: Schirmer, W. (Ed.), Holozäne Talentwicklung-Methoden und Ergebnisse. Geologisches Jahrbuch, vol. A 71. Bundesanstalt für Geowissenschaften und Rohshoffe, Hannover, pp. 11–43.

Schmitt, A., 1999. Jungholozäne Landschaftsentwicklung: der Wolfsgraben in Oberfranken. Master Thesis at the Institute of Geoecology, University of Potsdam, Germany.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., Mccormac, F.G., Plicht, J.U.M. Spurk (1998): INTCAL98, Radiocarbon age calibration 24,000–0 cal BP, Radiocarbon, Volume 40: 1041–1083.

Züchner, Ch., 1996. Die Steinzeit in Oberfranken. In: Abels, B.-U., Sage, W., Züchner, Ch. (Eds.), Oberfranken in vor- und frühgeschichtlicher Zeit: 2. Auflage. Bayerische Verlagsanstalt GmbH, Bamberg, pp. 25–64.